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THE STRENGTH OF OCCUPANT RESTRAINT SYSTEMS IN LIGHT AIRCRAFT - --ETC(U)
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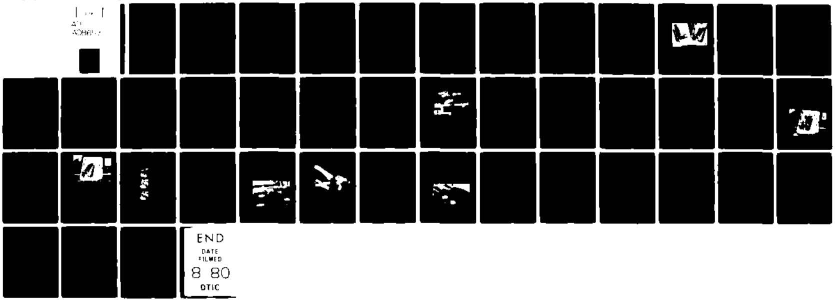

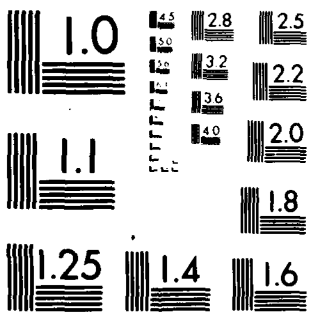

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MELBOURNE, VICTORIA

STRUCTURES REPORT 375

THE STRENGTH OF OCCUPANT RESTRAINT SYSTEMS IN LIGHT AIRCRAFT — AN EXPERIMENTAL EVALUATION

by

S. R. SARRAILHE

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(9) Final rept. (1976-1978)

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SUMMARY

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It was found that most restraint components were much stronger than demanded by the 9 g requirement and it was considered that only minor improvements would be needed to ensure 25 g capability. Seats were not as strong as the restraints and their behaviour under crash load conditions requires further investigation.

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16. *ABSTRACT*

The cabins and restraint systems of three cyclone-damaged light aircraft were tested statically to determine the strength of the restraint system in the cabin.

It was found that most restraint components were much stronger than demanded by the 9 g requirement and it was considered that only minor improvements would be needed to ensure 25 g capability. Seats were not as strong as the restraints and their behaviour under crash load conditions requires further investigation.

CONTENTS

1. INTRODUCTION

Typical design requirements[1] for light aircraft specify that:

"The structure must be designed to give each occupant every reasonable chance of escaping severe injury in a minor crash when".... "proper use is made of seats, belts and all other safety devices provided..."

Minimum design forces are specified for the restraints, for example, an inertia force of 9 g is assumed to act forwards on the occupant. This force is less than half that used in the design of motor vehicle restraints, and is probably very much less than the inertia force that could be withstood by the airframe or by an adequately restrained occupant. Snyder[2] has stated: "In effect we have 40 g occupants riding in 20 g aircraft protected by 9 g restraint/seat systems". The same report indicates that many fatalities which occur in potentially survivable accidents could be prevented by better crash protection.

Safety equipment is intended to provide "every reasonable chance of survival". Use of the word "reasonable" shows the basic compromise required in setting design objectives, either on a particular aircraft, or when setting design values, and a stronger restraint may be "reasonable" if it can be achieved by minor local reinforcement, e.g. a stronger attachment bolt, but may not be "reasonable" if strengthening the system would require extensive reinforcement of the fuselage structure.

Restraint configuration is important. The lap sash system has been shown to be much safer than the lap belt and it can be fitted in most light aircraft hence it would seem more "reasonable" than a lap belt.

Stronger restraints with upper torso protection seem desirable, but the decision to increase design forces or change the design requirements must balance the cost and the practicability as well as the desirability.

To provide information on the "practicability", tests were conducted on the cabins and restraint systems of several popular makes of light aircraft to determine the strength of the "tie down chain".

The tests also provided information which could be used for assessing design criteria because crash damage, occurring in similar aircraft, can be compared with test data to correlate crash severity with known test forces.

The tests using recent model aircraft fuselages were made economically possible by the availability of specimens from about 40 light aircraft wrecked by a tropical cyclone (Tracy) which devastated Darwin at Christmas 1974. The cabins of some of these aircraft escaped serious damage and five specimens were selected to represent the most popular types of high and low wing aircraft.

Most of the aircraft had been turned over by the storm, but the cabins of the high wing types had generally survived with little damage, and it was possible to select samples in which the doors would still open and close. The cabin roofs of nearly all the low wing types had been crushed and therefore it was necessary to accept samples with some damage in that region.

In all the cabins selected for testing, the floor, seat rails, and lap belt anchorages were undamaged. The appropriate seats and seat belts were also obtained for most of the aircraft.

In the tests a longitudinal crash deceleration was simulated by a static load applied to a body block, which represented an occupant, seated and restrained in the cabin. Tests proceeded

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Ref. 1—Federal Aviation Administration, Airworthiness Standards: Normal Utility and Aerobatic Aircraft Part 23 : 23.561. Department of Transportation, Washington, D.C. Sept. 1969.

Ref. 2—R. G. Snyder "Civil Aircraft Restraint Systems-State-of-the-Art Evaluaiton of Standards, Experimental Data and Accident Experience. Society of Automotive Engineers Paper 770154. Warrendale, Pa. 15096. March 1977.

to determine the strength of the restraint components, belt, seat and anchorages. Where possible, seats were also tested under simulated vertical loading.

The work was carried out as part of the Crash Safety Program supported by the Department of Transport (Air Transport Group).

2. TYPICAL DESIGN REQUIREMENTS

Until the early 1970's most light civil aircraft were only provided with lap belts. Upper torso restraint has been required in Australia[3] since 1972 and is also required in the United Kingdom.[4] Proposals by the American F.A.A. for the installation of upper torso restraint were circulated in 1973,[5] but the proposed rule has not been implemented[2] (as at 1977). Most new light aircraft can be fitted with upper torso restraint for the crew (as an option) but it is rarely available for passengers.[2]

The American design loading for the restraint system, seat, etc., is indicated by the Emergency Alighting Conditions shown in Table 1. Vertical loading in flight may exceed the emergency alighting condition and a typical seat requirement[6] is shown in Table 2. The ultimate inertia loading specified is applied to an occupant of mass 77 kg (170 lb) and a factor of 1·33 is applied to fittings and attachments. The main loadings are thus:

forward: 9 g* giving a force of 6·8 kN or 9 kN if the 1·33 factor is included (Table 1)
downward: 6 g giving a force of 4·5 kN or 6 kN if the 1·33 factor is included (Table 2)

TABLE 1
Emergency Alighting Conditions Normal Category Light Aircraft[1]
Inertia Loads Applied to an Occupant of Mass 77 kg (170 lb)

Direction	Inertia factor	Ultimate load kN	Factored(1) ultimate load kN
Forward	9	6·8	9
Sideward	1·5	1·14	1·5
Downward	3	2·27	3
Upward	3	2·27	3

Note 1: A special factor of 1·33 is applied to local attachments and fittings.

* In accordance with usual aircraft engineering and crash safety conventions, the symbol "g" is used to signify the ratio between the force exerted on an accelerating body and the weight of the body. (Weight is "the gravitational force acting on a body at the earth's surface".[7] An occupant mass of 77 kg corresponds to a weight of 756 N.)

Ref. 3—Airworthiness Advisory Circular No. 62, Department of Civil Aviation, Australia. March 1972.

Ref. 4—British Civil Airworthiness Requirements, Seats Safety Belts and Harness, Section K Chapter K4.Y, Paper 647 issue 1, Civil Aviation Authority, London. March 1975.

Ref. 5—Notice of Proposed Rule Making, Crashworthiness for Small Airplanes, Docket No. 10162 Notice 73·1. Federal Aviation Administration, Department of Transportation, U.S.A. Jan. 1973.

Ref. 6—National Aircraft Standards Committee Specification Aircraft Seats and Berths, NAS 809. Aircraft Industries Association of America, Washington, D.C. Jan. 1956.

Ref. 7—Chambers Dictionary of Science and Technology. T. C. Collocott (Ed.) W and R Chambers, Edinburgh, Scotland. 1971.

TABLE 2
Seat Strength Requirements[6]

Direction	Inertia factor	Ultimate load kN	Factored[(1)] ultimate load kN
Forward	9	6·8	9
Sideward	3	2·3	3
Downward	6	4·5	6
Upward	2	1·5	2

Note 1: A special factor of 1·33 is applied to local attachments and fittings.

The inertia forces are considered to be transferred to the restraint or seat by a "body block" and the inertia force is typically assumed to act approximately 260 mm above the base of the block. The body block rests on the seat and, for test purposes, should distribute the downward load "evenly over the seat bottom".[6] Distribution of load between the restraint anchorages and the seat is not usually detailed in the requirements, but the requirements for seat belts are usually detailed in separate standards.

Typically, the lap belt must withstand a tensile load of 6·7 kN (1500 lbf)[8,9] applied between the end fittings. The sash strap of a lap sash assembly is required to withstand from 2·2 kN[10] through 3·4 kN[3] to 4 kN.[11]

The specified strength of every component is less than that of the corresponding component in motor vehicles,[12,13,14,15] as shown in Table 3 and although some requirements suggest the desirability of structures which yield (or fail progressively with absorption of energy as occurs with a ductile component), this feature is neither mandatory nor quantified.

A draft U.S. military standard,[16] based on a study of survival in accidents reported in the Crash Survival Design Guide,[17] proposes greater strength, energy absorption and more realistic testing, including dynamic testing.

Ref. 8—Federal Aviation Administration Airworthiness Standards, Part 37–132 Safety Belts, Technical Standing Order TSO C22f, Department of Transportation. Feb. 1972.

Ref. 9—National Aircraft Standards Committee Specification 802, Aircraft Safety Belts, Aircraft Industries Association of America, Washington, D.C. May 1956.

Ref. 10—Advisory Circular No. 43-13-2 Change 2, Aircraft Effective 5.26.67 Federal Aviation Administration, Department of Transportation. May 1967.

Ref. 11—Draft Specification 13, Safety Belts with one Diagonal Shoulder Strap, British Civil Airworthiness Requirements Paper 662—Issue 1, Civil Aviation Authority, London. June 1975.

Ref. 12—Australian Design Rules for Motor Vehicles Safety, Rule 4c for Seat Belts, Australian Department of Transport, Melbourne. Feb. 1977.

Ref. 13—Australian Design Rules for Motor Vehicle Safety Rule 5b for Seat Belt Anchorages, Australian Department of Transport, Melbourne. July 1974.

Ref. 14—Dynamic Test Procedure, Type 1 and Type 2, Seat Belt Assemblies, SAE J 117, SAE Recommended Practice. Society of Automotive Engineers, Warrendale, Pa. Jan. 1970.

Ref. 15—Motor Vehicle Seat Belt Anchorage, SAE J787b, SAE Standard. Society of Automotive Engineers, Warrendale, Pa. Revised Sept. 1960.

Ref. 16—Draft Military Standard: Light Fixed Wing and Rotory Wing Aircraft Crashworthiness, MIL-STD-1290 (Av). Department of Defense, Washington, D.C. Jan. 1974.

Ref. 17—Eustice Directorate, U.S. Army Air Mobility Research and Development Laboratory, Crash Survival Design Guide, USAAMRDL Technical Report 71-22, Fort Eustice, Virginia. Revised Oct. 1971.

Snyder[2] cites an "Aerospace Recommended Practice" for "Occcupant Restraint Systems" (ARP 1226) and another for "General Aviation Seat Design" (ARP 1318) which were proposed by a committee (A-23) of the Society of Automotive Engineers, but were not approved by the Aerospace Council of the S.A.E. They were intended to lead to increased safety in accidents and suggested stronger (25 g) restraints and noted the interaction of the restraint and the seats (Table 3).

TABLE 3
Comparison of Design Values in Current Aircraft Requirements, Motor Vehicle Standards and Proposed Aircraft Regulations

Parameter[1]	Current aircraft	Motor Vehicle (Refs 12, 13)	Motor Vehicle (Refs 14, 15)	Proposed U.S. army aircraft (Refs 16, 17)	Proposed civil aircraft (Ref. 2)
Forwards inertia factor "g"	9[2]	23	30	30[3]	25[2]
Vertical inertia factor "g"	6[2]	0	0	48[4]	15[2]
Forwards design load kN	9	20+	27	N.S.[5]	N.S.
Lap belt loop load kN	13	22	22	36	N.S.
Inner lap anchorage kN	N.S.	11	13	18	N.S.
Upper torso/sash kN	3·4	9	7	18	N.S.

Notes 1: Parameters are defined differently in the various requirements, comparisons are therefore approximate.

2: Inertia factor acts on occupant's weight, motor vehicle values are cabin accelerations—the latter may produce greater forces on the occupant.

3: This value may be reduced if suitable energy absorption is provided.

4: Energy absorption is required.

5: N.S.—value not specified.

3. TEST METHOD

To determine the strength of the seat and restraint under forwards loading, a suitably shaped body block was mounted on the seat in the cabin, fitted with the seat belt and loaded by a hydraulic jack. A typical arrangement is shown in Figure 1. The aircraft cabin was secured to the laboratory floor. Loads applied to the body block and developed in the restraint were measured and recorded electronically. Displacement of the body block was also measured.

The load on the assembly was increased until the design load was achieved or damage occurred. In order to apply higher loads to the structure, after the initial failure, it was necessary to replace the broken parts with stronger or stiffer components. When this was done, care was taken to ensure that the direction of application of the load reproduced that in the assembly test. Ultimate loading of the seat belt anchorage was usually achieved by a linkage which applied load directly to the anchorage, but the loading exerted by the seat onto the floor was also represented.

To determine the strength of the seat under vertical loading a body block was pressed downwards into the seat in a direction approximately perpendicular to the seat surface. Care was taken to ensure that the body block was not supported unduly by the edges of the seat frame.

4. THE BODY BLOCK

The dimensions of the body block are shown in Figure 2. These were based on the recommendations of the Australian Standards Association,[18] and the Society of Automotive

Ref. 18—Seat Belts for Motor Vehicles, Australian Standard E35 Part 1–1970 Standards Associations of Australia, Sydney. March 1971.

FIG. 1. PIVOTED BODY BLOCK INSTALLED AND UNDER LOAD IN A LAP SASH RESTRAINT.

Engineers[15] for body blocks for testing automotive seat belts and anchorages, the National Aircraft Standards Committee[6] and the Crash Survival Design Guide.[17]

The base of the dummy, representing buttocks and thighs, rested on the seat to react the downwards load produced by the slope of the lap belt. It could also be used to apply down loads to the seat. The "thighs" were long enough to overlap the front of the seat, but were narrower than the seat frame to ensure that downwards load was supported by the cushion and seat pan and not by the seat frame.

The pelvis section was shaped to accommodate a lap belt and was keyed into the base. A fork attached to the pelvis section allowed for load application at the points shown B or C on Figure 2. When testing the lap belt anchorages, metal links were attached at B to simulate the belt and apply loads to the anchorages in the same directions as a belt.

The torso section, which was only used when testing assemblies with shoulder straps, was supported by a frame which pivoted on the fork at A. The pivot allowed the torso section to "pitch" relative to the base, and thus adapt to the slope of the seat and differential extensions of the shoulder and lap straps of the restraint. Load could be applied at any of a series of positions D-H to distribute the load between the shoulder and lap straps. Positions D and E correspond to the heights above the seat that are usually recommended, but as shown in the Appendix the load distribution with this pivoted body block was closest to that measured during dynamic tests[19,20] when loading position G, 305 mm above the base, was used.

5. AIRCRAFT "A"

5.1 Description

The aircraft has a low wing and accommodation for two occupants in separate, fixed seats located over the wing main spar. The seat and restraint arrangement is shown on Figure 3. The seat bases have tubular steel frames with a lattice of rubberized webbing straps covered by a cushion to provide the seating surface. The frame is supported at the front by short legs which are attached to the wing spar box. At the back the seat frame is bolted to a channel section anchorage which is riveted to a bulkhead. A cushion attached to this bulkhead provides the seat back.

A full harness (with twin shoulder straps) is provided for each occupant. The lap straps are attached to the channel sections which are used to mount the seat. The shoulder straps join behind the occupant's neck and are attached by a short steel cable to another channel section anchorage which is riveted to structure. Pairs of flat metal links are used to join the ends of the straps and the steel cable to the anchorages (Fig. 4).

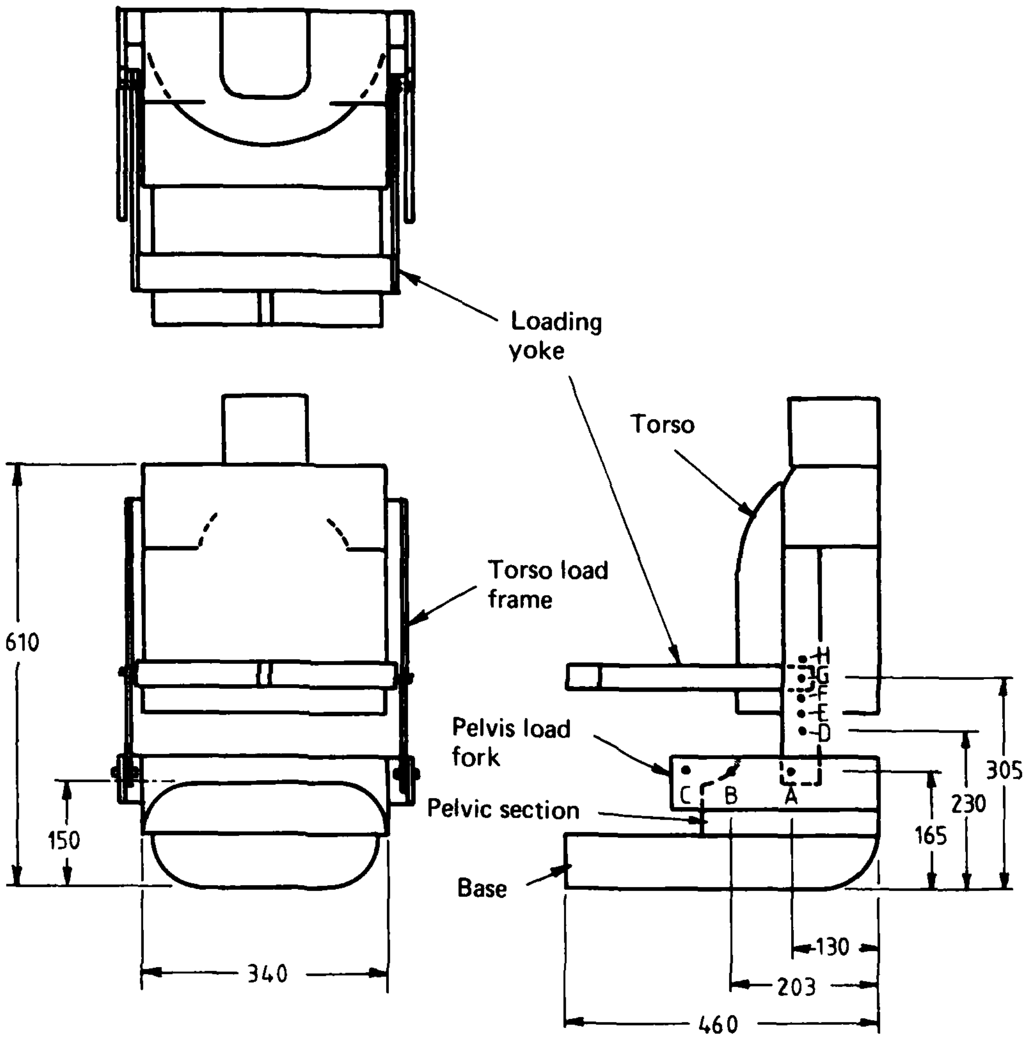
5.2 Test Procedure and Results

Tests were conducted to determine the load distribution, the behaviour under load or the ultimate strength of the following:

1. The assembly.
2. The seat and lap belt anchorage.
3. The lap belt connecting links.
4. The shoulder strap anchorage.
5. The shoulder strap connecting links.

Ref. 19—S. R. Sarrailhe. Dynamic Tests on a Yielding Seat Belt System. Structures and Materials Report ARL SM340, Aeronautical Research Laboratories, Melbourne. June 1972.

Ref. 20—S. R. Sarrailhe. Dynamic Tests on a Yielding Seat and Seat Belt System for Crash Protection. Structures Report 358, Aeronautical Research Laboratories, Melbourne. March, 1975.



Dimensions mm.

FIG. 2. BODY BLOCK – Torso pivoted on the pelvis fork at "A".
Alternative loading positions were C, B, D, E, F, G, H.

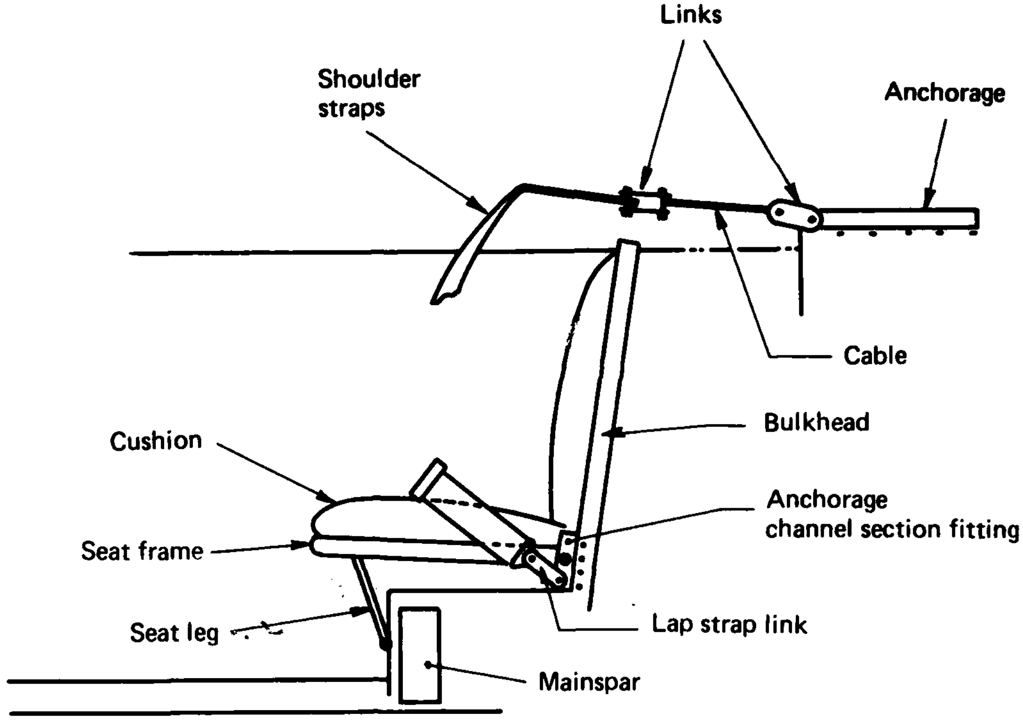


FIG. 3. LAYOUT OF SEAT AND HARNESS – AIRCRAFT "A"

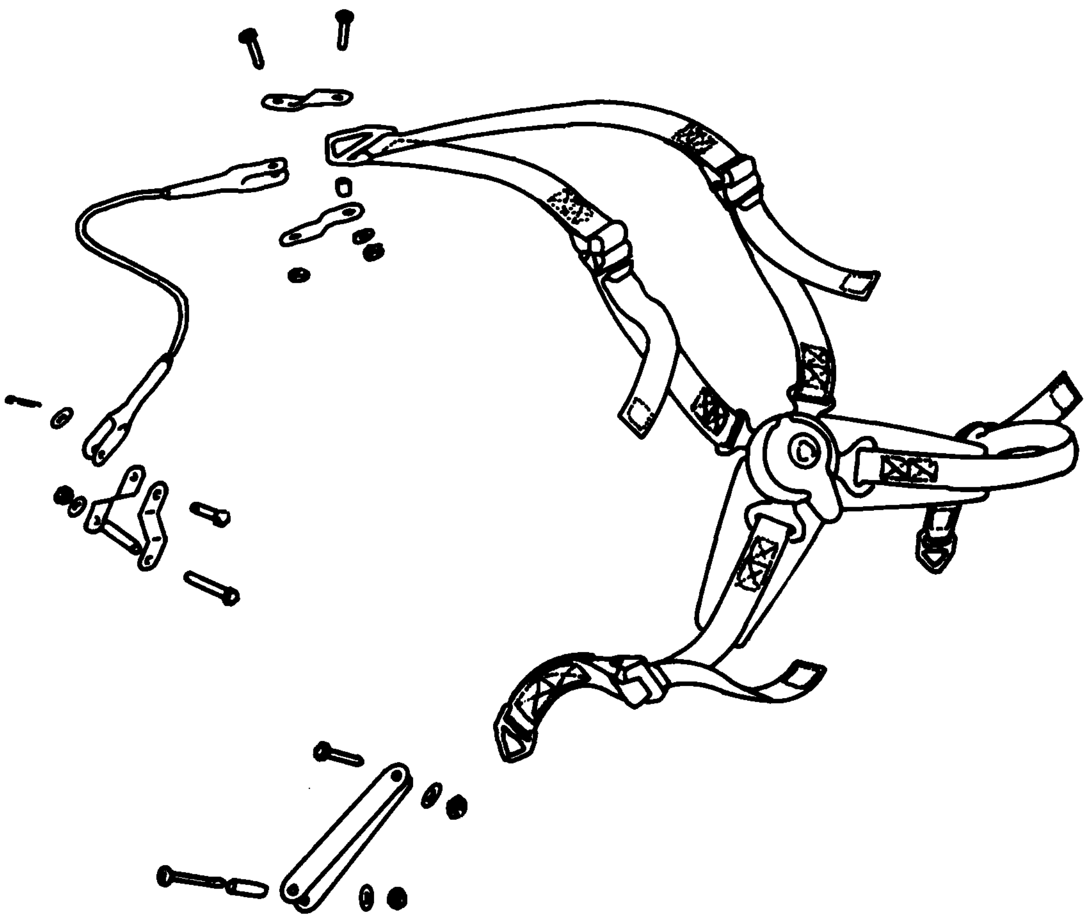


FIG. 4. RESTRAINT HARNESS AND ATTACHMENT LINKS – AIRCRAFT "A"

5.2.1 Assembly

The body block was mounted on the seat and fitted with the full harness. Load was applied to the body block in a forward direction 254 mm above the base. The load was increased until 11·4 kN was reached without apparent damage. Loading was discontinued to allow for inspection. The body block moved forwards about 220 mm during the test, but there was no measurable deflection of the anchorages. At the maximum forward load the combined load in the pair of shoulder straps was 3·2 kN and the tension in the inner lap strap was 4·0 kN. The tension in the outer strap was not measured because there was insufficient space for a load transducer; however, as the harness was symmetrical the tensions in both lap straps were probably the same in which case the sum of the strap tensions would have been very nearly equal to the applied load.

5.2.2 Seat and lap belt anchorage

The harness was removed and steel links were fitted between the body block loading frame and the lap strap anchorage to simulate the lap strap. The length of the links was based on the results of the assembly test to ensure that the direction of the loading at the anchorages represented the situation with the harness. Forwards acting load was applied to the body block and frame, and the downwards component of the lap strap load was reacted by the seat. The load in the inner lap strap and the applied load were measured. When the applied load reached 6·3 kN the front legs of the seat yielded and allowed the front of the seat frame to sink 20 to 30 mm. After this deflection the assembly could still react load and the test was continued until the inner lap strap anchorage failed. The maximum body block load was 10 kN and inner lap strap load was 5·3 kN. Failure occurred in a row of rivets which were loaded in tension and attached the anchorage to the bulkhead. The rivets in the outer lap strap anchorage were deformed and failure appeared imminent there also. There was negligible movement of structure before the rivets failed.

5.2.3 Lap belt connecting links

The connecting links between the strap and the anchorage were tested in tension. They were made from thin sheet metal and the failing load was affected by the degree of clamping provided by the joint. One pair of links tested with clearance on both sides of the lugs failed at 7·5 kN, but a pair lightly clamped to hold the link flat failed at 11 kN. With either arrangement the links were stronger than the anchorage.

5.2.4 Shoulder strap anchorage

A forward acting load was applied directly to the shoulder strap anchorage. Failure occurred at 7·6 kN across the bolt hole used to attach the shoulder strap links. There was negligible deflection before failure.

5.2.5 Shoulder strap connecting links

These were not available from the test cabin; however, a number of links had been tested in 1966. These had a typical strength of about 5·3 kN, but it was understood that a modification introducing stronger links was planned.

5.3 Discussion and Summary

A summary of the failing loads is given in Table 4.

The restraint provides a full harness, but the lap straps can be connected to provide a lap belt. The lap belt configuration resisted a body block load of 10 kN before failure and this corresponds to an occupant deceleration of 13 g.

When the shoulder straps are connected the load is shared by them and the lap straps and consequently the assembly can react a higher body block load than the lap belt alone. The test showed that the assembly could withstand 11 kN but the ultimate strength may be assessed

from the strength of the components and the typical load distribution. The assembly test indicated that the lap strap tension was approximately 35% of the applied load and that the tension in the shoulder straps was approximately 28% of the applied load. Under some conditions a greater proportion of the load could be carried by the shoulder straps, and it is considered that distribution of about one-third of the total load to each lap strap and the pair of shoulder straps would be typical. With this distribution, failure of the lap anchorage (and the old style shoulder strap links) at 5·3 kN indicates that the system would withstand an occupant load of 16 kN or about 21 g.

There was negligible deflection of the anchorages before failure.

During the test with the simulated lap belt the seat collapsed downwards by about 25 mm when the load reached 6·3 kN. The extent of this deflection was insufficient to have much effect on safety but space was still available for further movement of the seat and under downwards loading, this could allow useful energy absorption.

A study of some accidents to this type of aircraft showed that deformation of the seat legs, failure of the seat/lap belt anchorage at the riveted joint to the bulkhead and shoulder strap link failures had all occurred.

The seat was not tested under vertical loading.

TABLE 4
Summary of Results—Aircraft "A"
Forces at failure—Restraint with lap and upper torso straps

Component	Component load kN	Equivalent body block force kN	Equivalent occupant g.
Lap strap	—	—	25(1)
Shoulder straps	—	—	25(1)
Lap strap link	7·5+	23(2)	—
Shoulder strap link(3)	5·3	16(2)	21
Lap strap anchorage	5·3	16(2)	21
Shoulder anchorage	7·6	23(2)	30
Seat	—	—	13–20(4)

Lap belt only used

Lap strap anchorage	5·3	10	13
Seat	—	6·3	8·5(5)

Notes 1: Standard military-type harness.
2: Assuming one third of total body load at each anchorage.
3: Tests in 1966—stronger links may be fitted to current aircraft.
4: Estimated from test using lap belt.
5: Partial failure, after collapsing 25 mm seat continued to take load until anchorage failed.

6. AIRCRAFT "B"

6.1 Description

The aircraft has a low wing and seating for four occupants. The two front seats are adjustable in the longitudinal direction and the two rear seats are fixed. Lap belts are fitted for all occupants and sash straps were fitted for the front occupants (in the aircraft tested) so that the restraint

could be used as a lap belt or as a lap sash assembly. The sash anchorages may not have been original equipment. A layout of the front seats is shown on Figure 5.

The seats can slide along rails fixed to the floor and are attached to the rails by "claws" on each leg. The seat can be locked in any one of 7 positions by pins which are attached to each front leg and engage in holes in the rails as shown on Figure 6. The seat frame is fabricated from steel tube and the seat pan is formed by a lattice of natural fibre webbing. A plastic foam cushion is fixed over the webbing.

The location of the lap belt (relative to the seat in its mid position) is also shown on Figure 5. The outer anchorages are mounted on an aluminium alloy channel riveted to the side of the fuselage and the inner anchorages are mounted on the side of a "tunnel" which carries the control cables between the front seats. The belt end fittings are attached by bolts (5 mm (3/16 in) diameter) which pass through anchorage lugs into anchor nuts behind the mounting surface. The lugs are attached to the mounting surface by four solid rivets, each 3 mm ($\frac{1}{8}$ in) diameter. This is shown on Figure 7.

The anchorages for the sash strap were at the intersection of a stiffener in the roof and the frame immediately behind the door. The anchorage bolt was fixed to a gusset which was bolted to the stiffener and frame. The arrangement is shown on Figure 8. Extensive damage of the roof and frame prevented testing of the sash anchorage in their correct positions.

The rear seats were formed by cushions attached to a plywood panel which extended between the wing main spar carry through box and a frame which supported the flap controls. The lap belts were attached to this frame by short cables which passed through holes in the plywood. One side (the right) of this frame was damaged. This prevented testing of the right hand assembly and may have reduced the strength of the inner anchorages.

6.2 Test Procedure and Results

Tests were conducted to determine the load distribution, behaviour under load or the ultimate strength of the following:

1. The front seat assembly.
2. The front seat lap belt anchorages.
3. The front seat sash anchorages.
4. The front seat restraint.
5. The front seat under vertical load.
6. The front seat anchorages.
7. The back seat assembly.
8. The back seat lap belt anchorages.

6.2.1 Front seat assembly

The left front seat was locked in the mid position of its fore and aft adjustment. The body block was positioned on the seat and a webbing strap fitted to represent the lap belt. Transducers were used to measure the total applied load and the tensions in the strap. Load was applied in a forwards direction and incrementally increased to a value of 7·5 kN. Although no failures had occurred, there was considerable deflection which resulted in the transducers contacting the seat frame. As further loading could have damaged the transducers, the test was discontinued and the webbing strap replaced by steel links incorporating more compact transducers. The links reproduced the geometry previously measured at the load of 7·5 kN. Loading was continued until the applied load reached 24·5 kN. The test was terminated to allow inspection of the structure and again no damage was found. Strap tensions at the achorages were each approximately 40% of the applied load.

6.2.2 Front seat lap belt anchorages

Loading of the anchorages was continued by applying load to each anchorage in turn. In the first test the direction of loading was that indicated by the assembly test (43° to the horizontal) but in subsequent tests the directions were chosen to represent the slope of the belt with other seat positions.

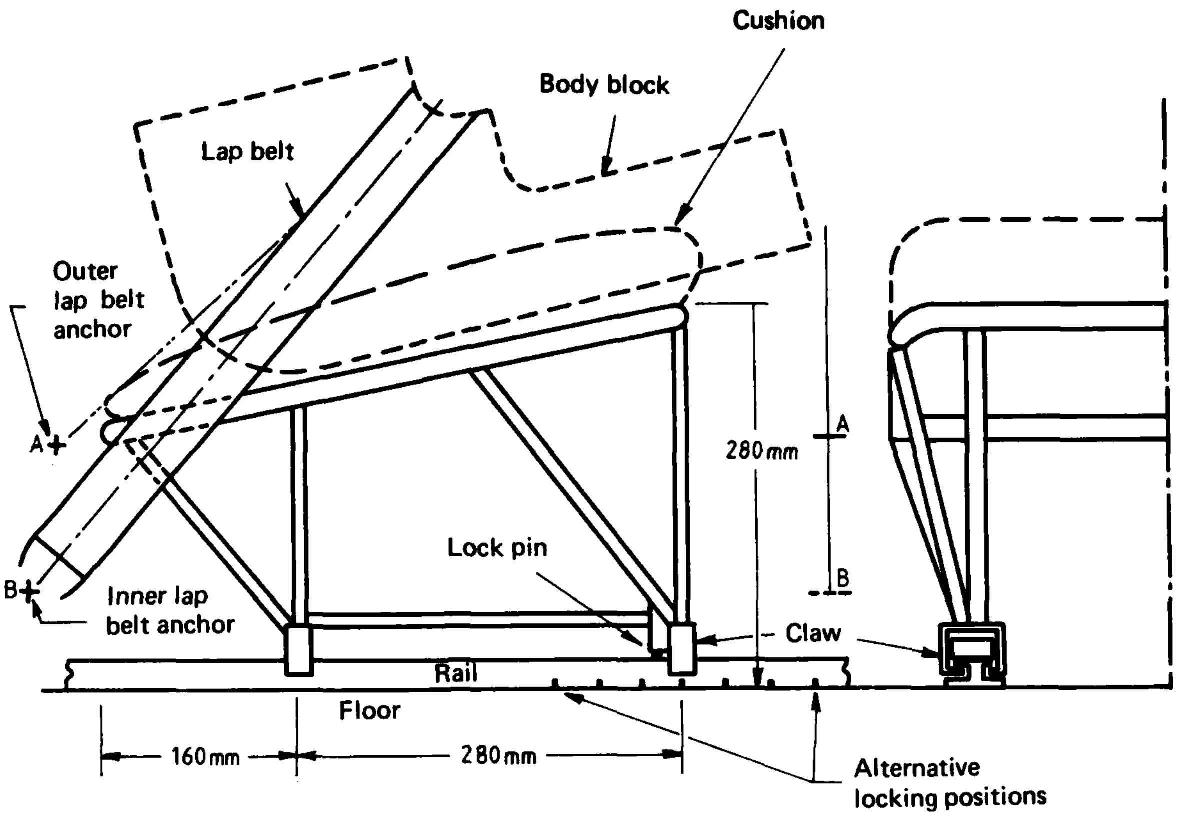


FIG. 5. LAYOUT OF FRONT SEAT AND LAP BELT – AIRCRAFT "B"

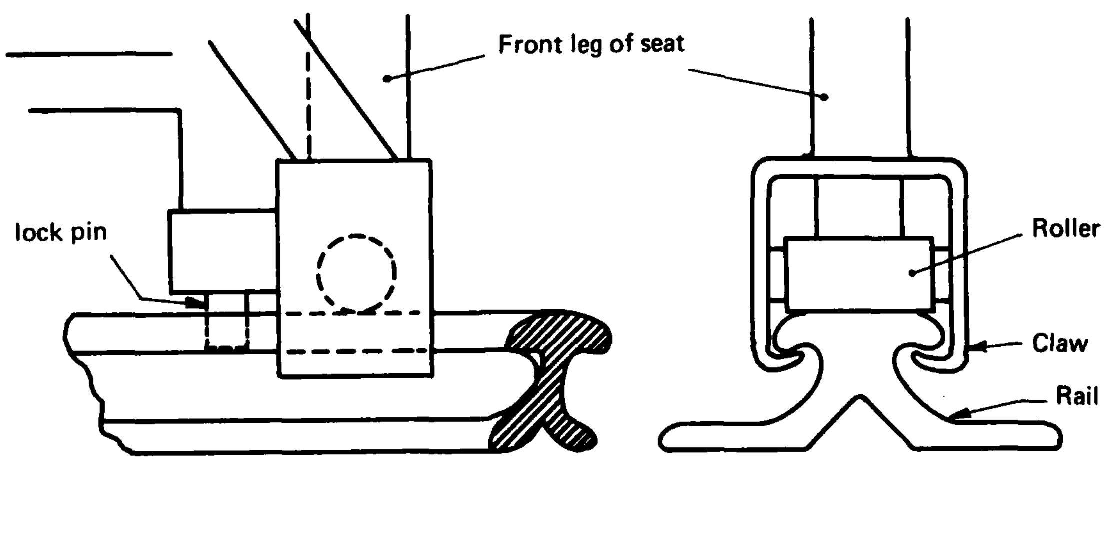


FIG. 6. ATTACHMENT OF LEGS OF FRONT SEAT TO THE RAIL – AIRCRAFT "B"
(LOCK ON FRONT LEGS ONLY)

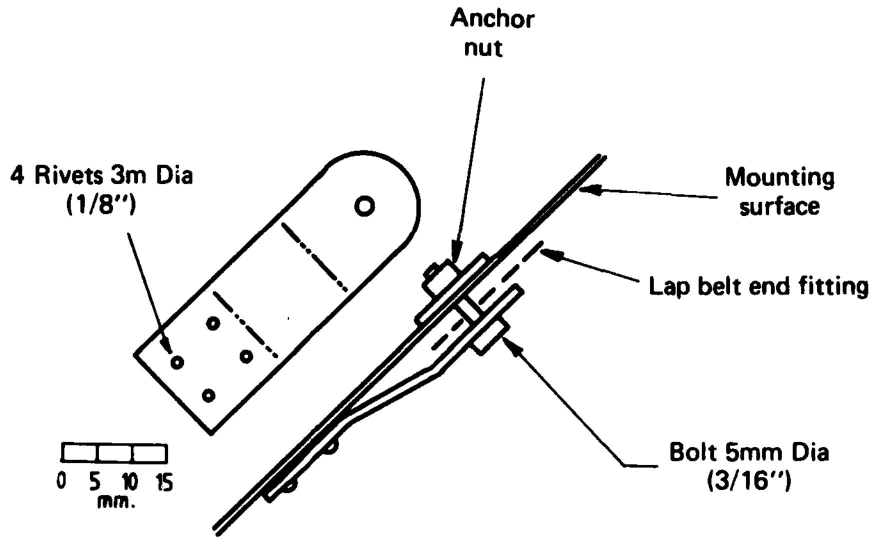


FIG. 7. LAP BELT ANCHORAGE – "AIRCRAFT "B"
(TO MEMBER ON FUSELAGE SIDE OR "TUNNEL")

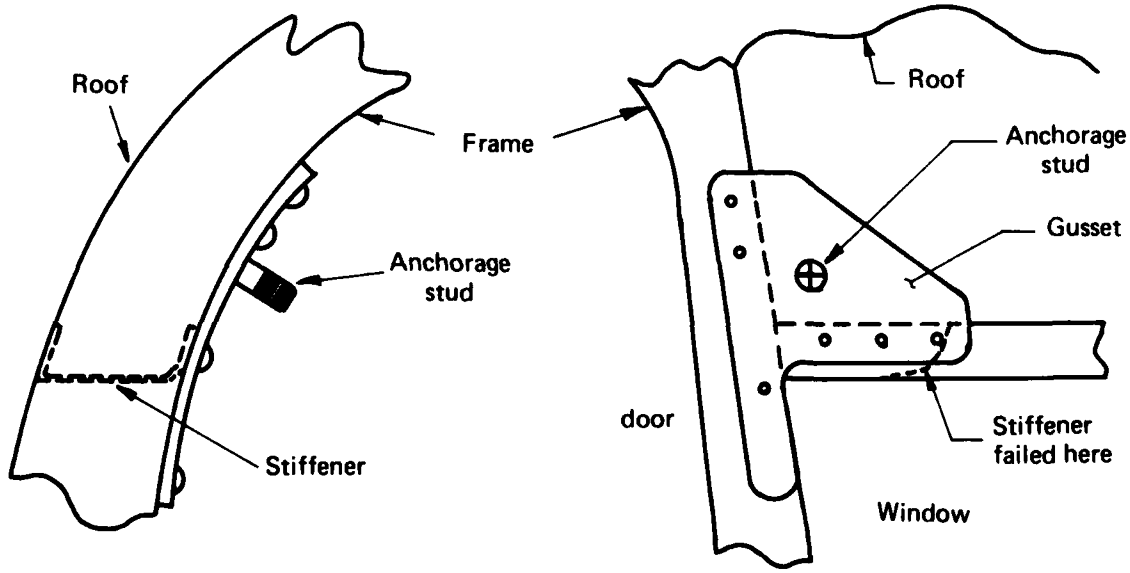


FIG. 8. SASH ANCHORAGE – AIRCRAFT "B"

The anchorages for the belts of both front seats were tested and the lowest failing load was 10 kN (i.e. approximately the value reached in the assembly test) and the highest, 15 kN. Results are shown in Table 5. In each case failure was by shearing of the four rivets which attached the anchorage to the mounting surface.

TABLE 5

Strength of Lap Belt Anchorages, Front Seating Position—Aircraft "B"

Belt slope and maximum applied load in the assembly test and belt slope and failing loads when the anchorages were tested individually

Test	Inner anchorage		Outer anchorage	
	Slope Degrees	Load kN	Slope Degrees	Load kN
Assembly test	42	10	33	11
Individual test to failure:				
Left hand seat	43	15	27	10
Right hand seat	45	13·6	30	11

6.2.3 Front seat sash anchorages

The shoulder anchorages were tested by fixing the skin of the cabin roof to a loading frame and applying load to the anchorage in a "forwards" direction (relative to the aircraft). The stiffener to which the anchorage was attached failed at approximately 4·5 kN. It is possible that the previous damage to the frame affected the stress distribution in the stiffener and that with an intact structure the anchorage would have reacted a greater load. As the installation was probably made after the aircraft left the manufacturer the strength may not be representative of all aircraft of the type.

6.2.4 Front seat restraint

The restraint system was loaded in tension in a universal testing machine. The inner and outer lap straps of one seat belt assembly were joined by the buckle and tested in tension. Failure occurred in the end fitting as shown on Figure 9*a* at a load of 9·6 kN. The other assembly was connected to test the lower sash strap, the sash lap joint and the inner lap strap. This assembly shown on Figure 9*b*, failed in the webbing at the adjuster at a load of 8 kN. Finally the upper sash and inertia reel were tested. The reel was anchored, locked manually and tension applied to the strap. The pawls slipped at 4 kN allowing the strap to extend, but when the pawls were re-engaged and load re-applied, the reel withstood a tension of 9·8 kN before the spindle failed, shown on Figure 9*c*.

A minimum strength of 8 kN in the inner lap strap implies that the restraint assembly would withstand a total force of 20 kN either as a lap belt, with the distribution measured in the assembly tests, or as a lap sash with the typical load distribution shown in the Appendix.

6.2.5 Front seat under vertical load

The resolution of the forces exerted onto the seat by the body block during the assembly test is shown on Figure 10. The applied load of 24·5 kN and the tension from the seat belt produced a resultant of 13 kN. The forward and downwards components of this resultant were 8 and 11 kN, respectively.

The line of action of the resultant was very close to the seat frame so that although there was a downwards load on the seat, the seat "pan" was not loaded. To test the pan a

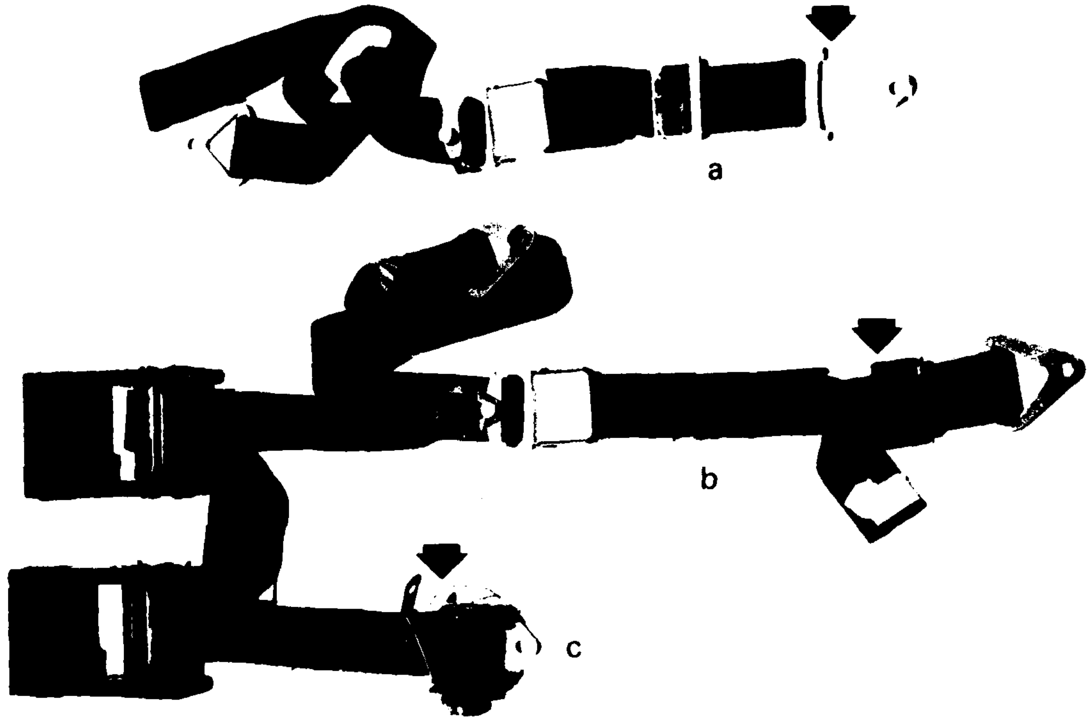


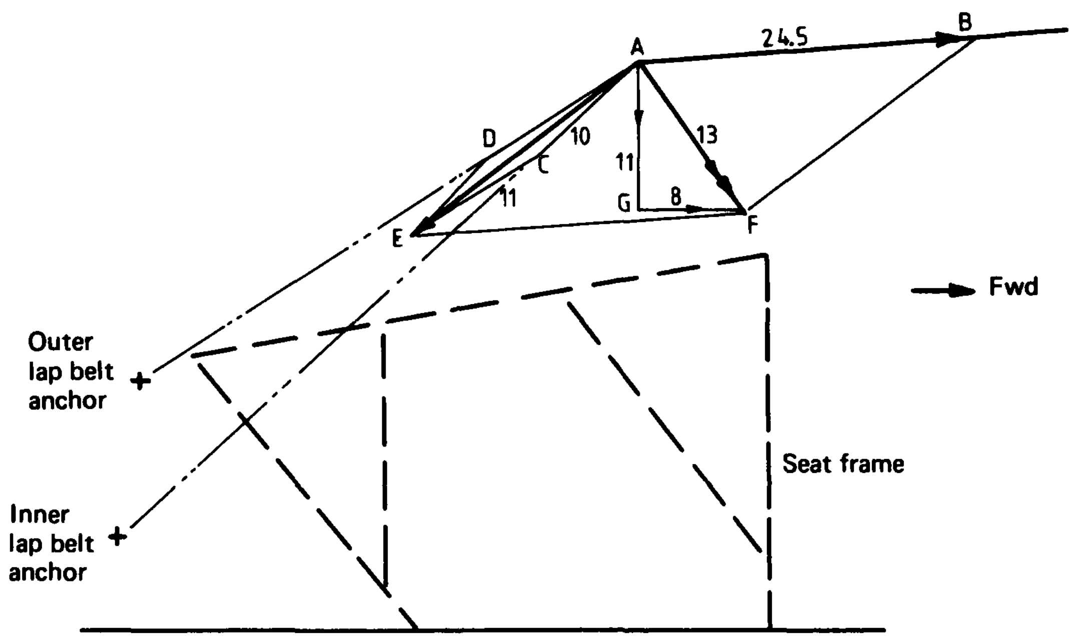
FIG. 9. RESTRAINT ASSEMBLIES – AIRCRAFT "B"

a Assembled as a lap belt.

b Assembled to test lower sash, sash to lap strap joint and lower lap (loaded with webbing grip).

c Assembled to test reel and upper sash (loaded with webbing grip).

Points of failure indicated by arrow.



AB Applied body block force 24.5.kN

AC Inner lap strap tension 10kN

AD Outer lap strap tension 11kN

AE Resultant lap strap tension 21kN

AF Resultant force onto seat 13kN

AG Downwards component of seat force 11kN

GF Forwards component of seat force 8kN

FIG. 10. RESOLUTION OF FORCES ACTING ONTO THE BODY BLOCK AND SEAT

"downwards" load was applied to the seat surface by the body block, Figure 11. The seat surface is inclined at approximately 15° to the horizontal and the load was applied approximately at right angles to the seat surface; thus, although the load was predominantly downwards, it had a small forwards component. The line of action was 150 mm from the back of the body block and 175 mm from the rear cross member. The body block overhung the front of the seat, but elsewhere was inside the perimeter of the seat frame.

The body block was pulled down into the seat by a hydraulic jack and a linkage which passed outside the seat frame and through the floor. The fuselage was supported under the main spar and under the nose, in front of the cabin.

The maximum load that the seat could react was 10 kN. The deflection at this load was 50 to 70 mm from the "static position" (e.g. the position with a weight of 750 N on the seat resulting from the mass of the man). After the test it was found that all the longitudinal webbing straps and the rear transverse strap had broken.

Several sections of strap were tested in tension and these failed at loads of 1·8 to 2·2 kN. The natural fibre of the webbing was discoloured and it is probable that some degradation had occurred. The seat frame was not distorted.

6.2.6 Front seat anchorages

The strength of the anchorage of the seat under forwards loading was determined by mounting the seat on the rail and applying a forwards load to the top of one front leg. The lock pin on that leg was engaged in the seat rail. The lock failed in two stages, first the pin bent which allowed the seat to move a few millimeters, but the pin then jammed allowing a further increase in load to 6·6 kN when it failed completely and allowed the seat to slide along the rail. To check this behaviour a second pin was tested in a simulation of the assembly, but with the load applied very close to the top surface of the rail to minimize any friction forces which could relieve the load on the pin. The pin failed at 6·6 kN as in the previous test. (Note that the horizontal force on the seat in the assembly test was 8 kN, but this was shared by two locks.)

When the forward load was applied to the top of the leg, the rear claw would have been subjected to an upwards load of approximately 5·5 kN. This did not disengage the claw. A detail test was carried out with the claw of one front leg attached to a short length of rail. An "upwards" load was applied and the claw disengaged from the rail at a load of 5 kN.

6.2.7 Back seat assembly

The body block was positioned on the back seat cushion, on the left side of the aircraft, and restrained by the aircraft lap belt. A forwards acting load was applied to the body block, and increased until failure occurred in the steel cable joining the outer lap strap to the under floor structure. The load at failure was 15·8 kN.

6.2.8 Back seat lap belt anchorages

The inner lap straps for both rear seat occupants were attached by a steel cable to the same structural member. To simulate simultaneous loading from both occupants the two inner lap strap cables were connected to a hydraulic loading system and load applied. A load of 11·3 kN was reached before the structure failed. The structure in the region of the anchorage had been damaged in the cyclone and an undamaged structure would certainly have reacted a greater load. Assuming the body block load to be divided equally between the inner and outer lap straps, the result indicates that the system would withstand a body load of at least 11 kN applied simultaneously at each of the rear seat positions.

6.3 Discussion and Summary

The failing loads reached in these tests are summarized in Table 6.

The lap belt for the front seat occupant withstood the equivalent of 20 kN forwards load (28 g) which is more than three times the specified "emergency landing" condition (6·8 kN). The seat and anchorages withstood an even greater forwards load of 24·5 kN.

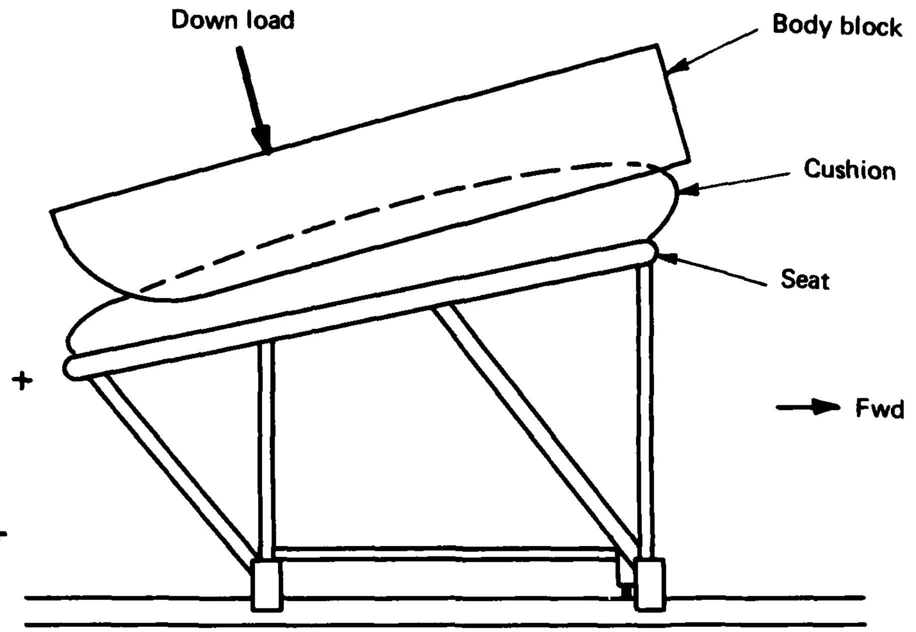


FIG. 11. THE FRONT SEAT UNDER "VERTICAL" LOADING

The sash anchorages withstood loads in excess of 4 kN which with typical load distribution would correspond to a total body block load of about 10 kN (13 g), but it is noted that they may have been weakened by damage caused by the cyclone. It is also noted that the installation may have been non-standard.

The webbing seat pan withstood a vertical load of 10 kN (13 g) which is nearly twice the specified load.

The lap belts provided for the back seat occupants withstood a forwards acting load of 15 kN applied to the installation to represent a single occupant in one of the two back seats. Testing of the two seat belt installations simultaneously would have been desirable, as the inner lap straps from both assemblies attach to a single piece of structure. Unfortunately, this was not possible because of cyclone damage, but simulation of the loading of the centre anchorages indicated that they would withstand at least 11 kN (or 15 g) on each of the two rear seat occupants.

TABLE 6
Summary of Results—Aircraft "B"

Component	Loading	Component failing load kN	Equivalent body load kN	Equivalent[1] "g"
Front seat				
Seat and lap anchorages[2]	assembly	—	24	31
Lap belt	tension	8	20	26
Lap sash restraint (inner lap)	tension	8	20[3]	26
Lap anchorages	direct	10–15	24+	31
Sash anchorage	direct	4+	10[3]	13+
Front seat locks each	direct	6·6	24+	31
Front seat claws	direct	5	—	—
Down load on seat	direct	10	10	13
Back seat				
Lap belt installation, one occupant	assembly	—	15	19
Lap belt inner anchorages for both occupants simultaneously	direct	11+	11+	15+

Notes 1: Occupant mass 77 kg, weight 760 N.
2: Simulated lap belt.
3: Assuming typical load distribution as described in the Appendix.

7. AIRCRAFT "C"

7.1 Description

This was a single engine aircraft with a strut braced high wing. It was representative of a series of aircraft, from one manufacturer, of basically similar design which form the most numerous group of related aircraft in Australia. Together they make up about a third of the light aircraft population. Most types in the series have fixed landing gear, but in the model tested the gear retracted into the underside of the fuselage.

Accommodation was provided for four occupants. The two front seats were adjustable in the longitudinal direction, but the bench seat for two rear occupants was fixed to the floor. Lap belts were provided for all occupants and, in addition, sash straps were attached to the door pillars so that the front seat occupants could use the lap belt by itself or with the sash to make a lap sash assembly. (The front seat belt assembly was of a type made in Australia.)

Each front seat could slide on rails attached to the floor and could be locked in any of ten positions by a single pin which was attached to the front leg and engaged in holes in the rail.

The seat frame was constructed of steel tube with triangulated bracing. The seat installation is shown in Figure 12. The seat pan was formed by four "Z" springs (three of 10 gauge wire and one of 12 gauge wire) covered by a sheet of canvas, a foam cushion and the upholstery fabric.

A later type of seat, fitted in aircraft in this family, is constructed from rectangular aluminium alloy tubing. No sample of this type was available.

The location of the lap belt anchorages relative to the seat, when the seat was at mid position is shown on Figure 12, and it is seen that the lap belt is nearly vertical. The attitudes of the belt with the seat fully forwards and rearwards and the geometry of the seat frame are shown in Figure 13.

The lap belts provided for the rear two occupants were attached to the back seat. The seat frame was made from steel tube and had short legs which were attached to the raised floor over the wheel bay. Attachment was by eight bolts engaging anchor nuts at the sides and centre line of the fuselage. The bolts at the back of the seat were close to the lap belt attachments on the seat. The seat back could fold forwards and like the front seat, the seat pan consisted of a series of "Z" springs covered by a foam cushion.

7.2 Test Procedure and Results

Tests were conducted to determine the load distribution, behaviour under load or the ultimate strength of the following:

1. The front seat assembly.
2. The front seat lap belt anchorage.
3. The front seat sash anchorages.
4. The front seat restraint.
5. The front seat under vertical load.
6. The back seat assembly.
7. The back seat anchorages.

7.2.1 Front seat assembly

The left hand seat was locked at the fifth position from the front and the lap/sash assembly and seat were tested under simulated forwards inertia loading by applying a forward load to the body block. The assembly is shown on Figure 12. Load was applied at position G on the loading frame as indicated by the tests described in the Appendix.

As load was applied, the body block moved forwards but the lower section moved more than the torso section, so that at a force of 2 kN the "hip" had moved 100 mm whilst the shoulder had only moved 25 mm. This was mainly caused by the very steep slope of the lap belt in the installed condition, because the straps were unable to react the horizontal loading until they had adopted a shallower angle. The differential movement of the hips and shoulder resulted in the torso tipping backwards and, when the applied load was just over 8 kN, the shoulder strap slipped across the neck and off the body block.

The condition just before this happened is shown on Figure 14. Body block load was 8 kN and the tensions in the inner and outer lap straps were 3 kN and 1·8 kN, respectively. Resolution of the applied load and strap tensions indicated a reaction between the dummy and seat of about 4 kN. The position and directions are indicated on Figure 15, where it is seen that most of the load would have been applied to the seat front cross bar.

The seat and floor deflected slightly, but no failures were evident.

To determine the strength of the seat and lap belt, the shoulder strap and torso section of the body block were removed and the load point was moved to position B. Vertical and horizontal deflections at point B were measured As the forwards acting load was applied, the body block moved forwards and down, approximately in an arc centred on the lap strap anchorage. A discontinuity in the load deflection relationship at about 5 kN indicated partial failure, but the system continued to react load until at a load of 9 kN it was evident that part of the seat frame had failed and that the inflexible body block was being supported by the sides of the seat frame in an unrealistic way. The assembly was unloaded and the front cross bar of the seat was found to be broken next to the front leg, at the position shown on Figure 16. This was the position of maximum bending moment and in addition, the tube was weakened by a hole which located a seat spring.

FIG. 12. LAP SASH RESTRAINT SYSTEM TEST IN THE CABIN OF AIRCRAFT "C"

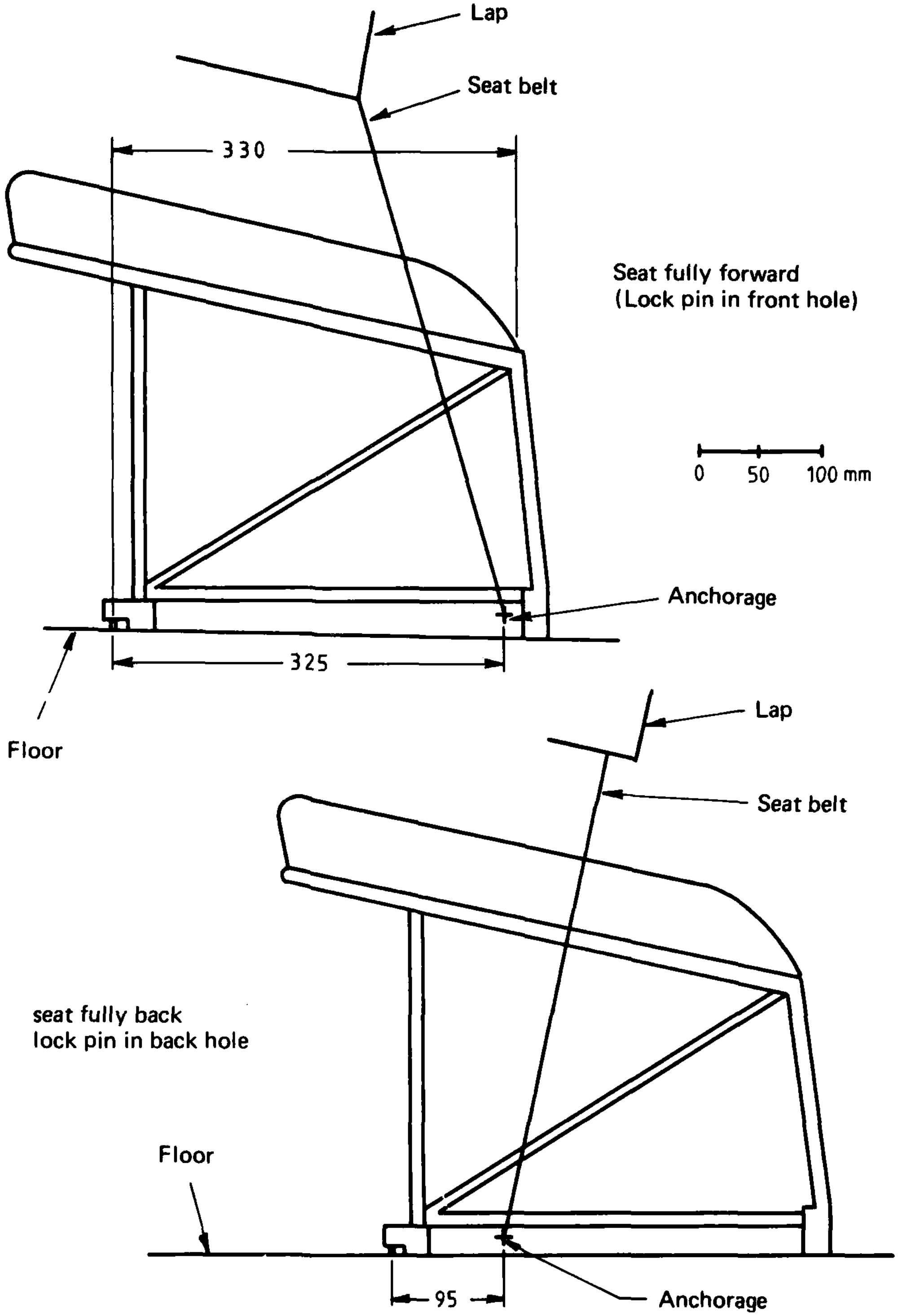


FIG. 13. LAP BELT SLOPE WITH SEAT IN FORWARD AND FULLY BACK SEATING POSITIONS FOR AIRCRAFT "C"

Note: Seat can slide further forward or backwards for ease of access.

FIG. 14. RESTRAINT SYSTEM UNDER LOAD OF 8kN IN AIRCRAFT 'C'

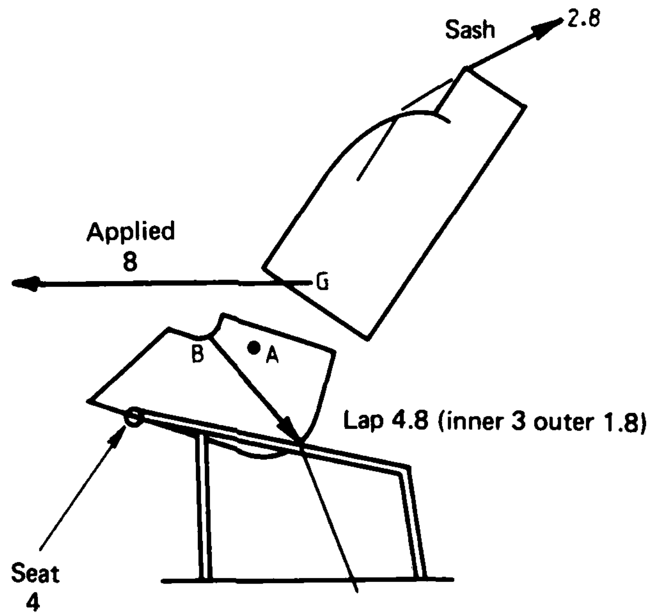


FIG. 15. RESOLUTION OF FORCES ONTO THE BODY BLOCK IN AIRCRAFT 'C'

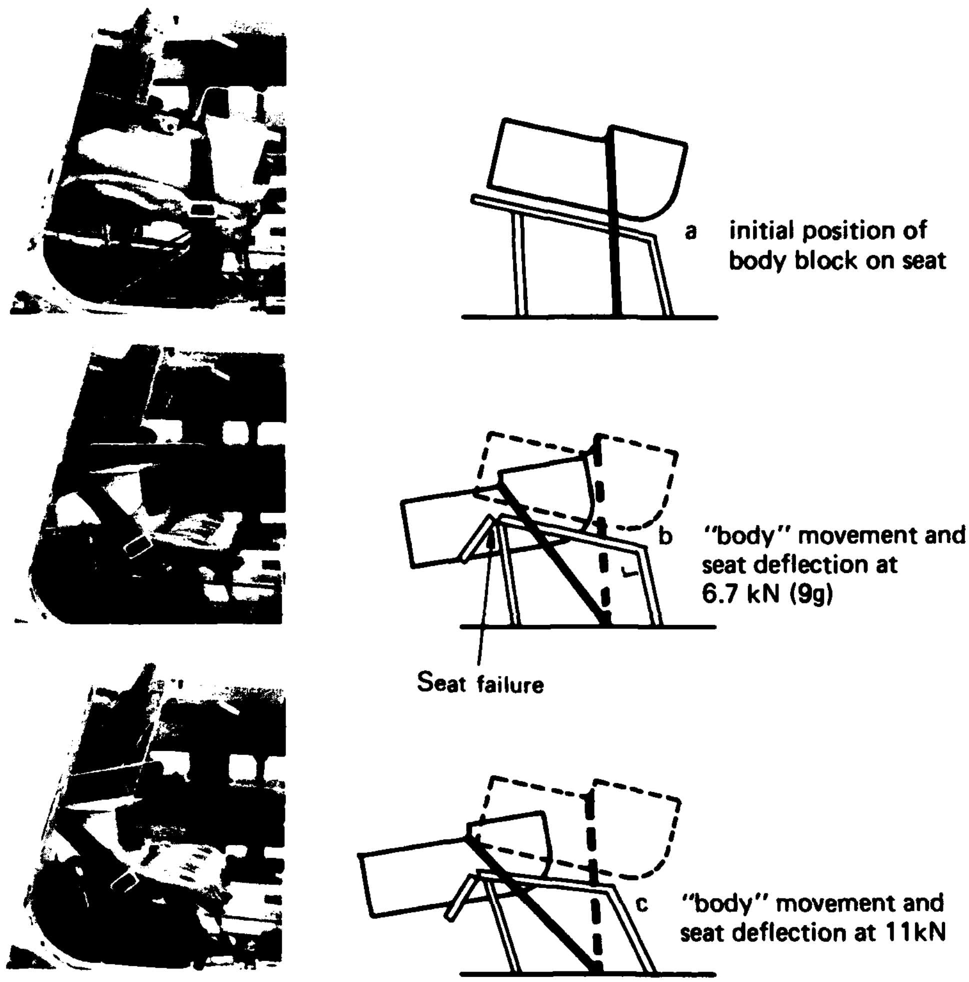


FIG. 16. SEAT AND BODY BLOCK DISPLACEMENT – AIRCRAFT 'C'

The test was repeated on another similar seat and failure of the cross bar occurred at a forward load of 4 kN. As a further check and to determine behaviour after the failure of the cross bar, the first seat was repaired and tested with a revised body block. This had a width of 330 mm and smooth sides to prevent it catching on the seat frame, as shown on Figure 16.

The repaired cross bar failed when the forwards load reached 4 kN; forwards movement of the body block was then 200 mm from the initial position. Loading was continued and the body block was pressed deeply into the seat. At 6·7 kN (9 g) the forward movement was 300 mm (Fig. 16*b*). At 11 kN, forwards deflection was 350 mm (Fig. 16*c*), and the sides of the seat frame were pulled in against the sides of the body block. This lateral compression was caused by the lap belt which was outside the seat frame. It was considered that the clamping effect provided more support for the body block than it would for a human and the test was discontinued. The large forwards deflection of the seat is evident on Figure 16, and whilst some distortion was caused by earlier tests, most occurred in the last test at loads in excess of 7 kN. The longitudinal seat adjustment lock pin on the left front leg withstood all loads applied, but locking of the seat on one side only resulted in the seat twisting under load and the legs on the right hand side moved forwards on the rails.

In all the tests with a lap belt, the tension in each strap was approximately half the forward load, thus the loop load from both straps was about equal to the forwards load. The lap strap slope varied during the test from the nearly vertical condition, shown on Figure 16*a*, to about 45° as shown on Figure 14*c*; however, at the design load (6·7 kN) the slope of the belt was approximately 60°. It follows that the resultant load on to the seat would also be approximately equal to the forward load, as shown on Figure 17.

7.2.2 Front seat lap belt anchorages

When the lap belt anchorages were tested the body block was supported by a wooden platform to represent the seat, steel links were used to represent the straps and the body block was mounted on rollers to minimise friction. The loads in the links were measured. The load was applied to the body block as in previous tests, but the roller mounting altered the relationship between the applied load and "strap" tension. At a link load of 9·2 kN the inner anchorage failed, tearing out of the floor as shown on Figure 18. The installations of the inner and outer anchorages were similar and so they are likely to be equally strong. Based on the load distribution measured in the assembly tests, this strength would correspond to forward loads on the occupant of approximately 18·4 kN if restrained by a lap belt only or 24 kN if the lap sash assembly is used.

7.2.3 Front seat sash anchorage

The top part of the sash strap and anchorage were tested together by loading the strap directly in the direction indicated by the assembly test. The strap end fitting failed at a strap tension of 10·8 kN but the anchorage was only slightly distorted. This corresponds to an occupant load of about 27 kN.

7.2.4 Front seat restraint

The restraint system was loaded in tension in a universal testing machine. The inner and outer lap straps were joined by the buckle and tension applied. The webbing of the outer lap strap failed at the end fitting at a load of 7·1 kN. The test was continued by loading the outer strap with a webbing grip until the webbing of the inner strap failed at the end fitting at a load of 12·5 kN. Both fittings were rusty and the webbing was dirty, these factors may have reduced the strength, but the difference in failing load between the two ends is considered to be due to the different shapes of the slots in the end fittings, shown on Figure 19.

The upper end of the sash strap had been used in the test of the sash anchorage and the end fitting had failed at 10·8 kN. The lower end of the sash is joined to the buckle by a slotted end fitting which fits over the buckle tongue before it is inserted into the buckle. These connections were made and tension applied to the sash and inner lap strap using webbing grips. The sash webbing failed where it passed through the lower end fitting. Typical load distributions as shown in the appendix indicate that the restraint could withstand 14 kN as a lap belt or 27 kN as a lap sash assembly.

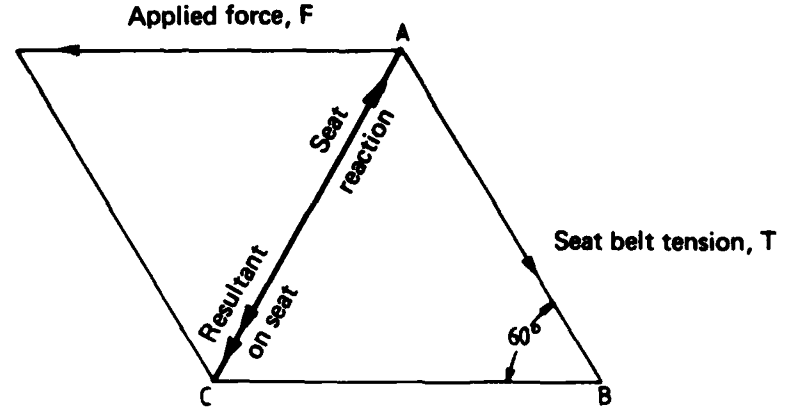


FIG. 17. RESOLUTION OF FORCES IN THE SEAT AND SEAT BELT.
As F and T are equal (measured in test) and seat belt slope was 60°, triangle of forces ABC is equilateral, thus the seat reaction is also equal to F.

FIG. 18. FAILURE OF THE INNER LAP STRAP ANCHORAGE (9.2kN) – AIRCRAFT 'C'

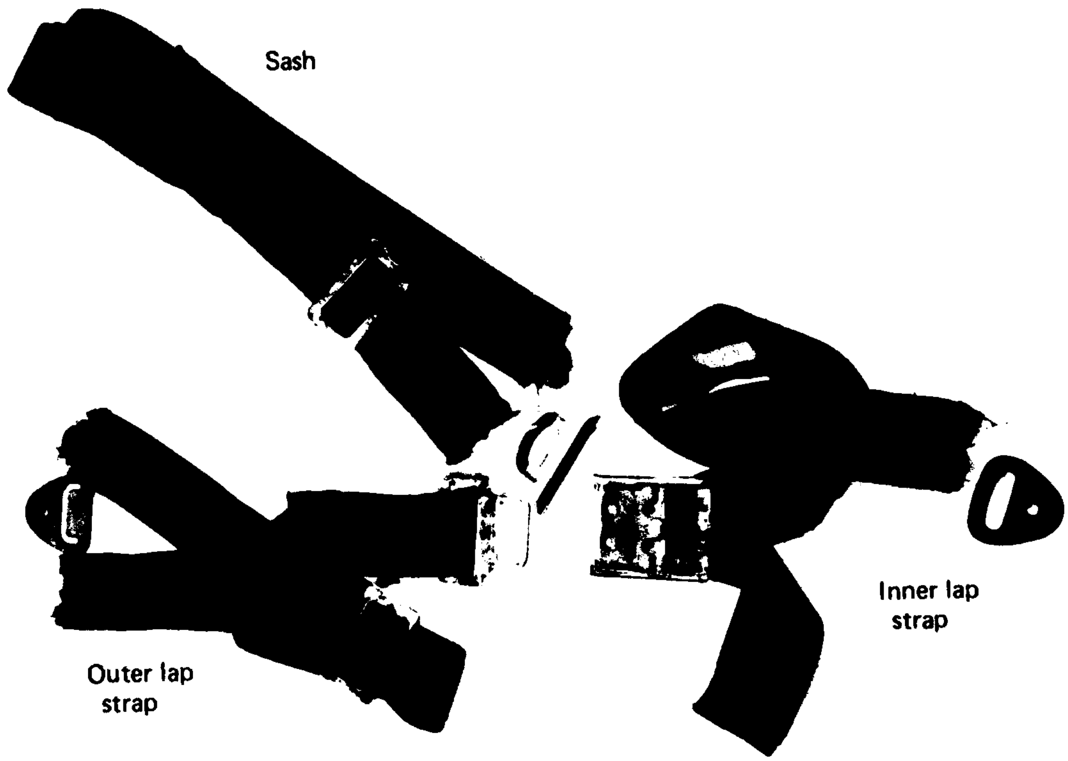


FIG. 19. RESTRAINT FRONT SEAT AIRCRAFT 'C'. The buckle cover was removed.

7.2.5 Front seat under vertical load

As the frame of the seat base had been broken in the longitudinal load test, the frame from a seat back which was dimensionally similar, was adapted to represent the seat base by fitting the appropriate springs and upholstery.

A body block only 250 mm wide, was used to ensure that it did not catch on the sides of the frame.

The body block was pressed on to the seat cushion and the load and deflection were measured as it was forced through the seat frame until an occupant would have reached the floor of the aircraft. The fabric of the upholstery started to tear at a load of about 3 kN. The load reached 5 to 6 kN before the fabric failed completely. Loading was continued and the springs, acting as tension links or straps, reacted a force of about 5 kN as the body block was pressed through the seat. The force deflection characteristics are shown on Figure 20.

7.2.6 Back seat assembly

The back seat with eight attachments could be considered as two halves one for each occupant, with their own attachments, accordingly it was attached using four bolts and one occupant position was loaded, by the body block, in the forwards direction. The inner rear attachment failed when the body block load reached 10·3 kN. The failure was at the bolt hole in the foot, where it was weakened by a slot cut from the bolt hole to the edge of the foot, presumably to facilitate installation. The sides of the slot were uneven suggesting that it had been hand worked after manufacture of the seat.

The outer lap strap and anchorage were tested by applying a load directly to the strap and the webbing failed at a load of 11 kN.

7.2.7 Back seat anchorages

The seat was removed and the inner anchorages tested by applying load directly to the two bolts. The load was applied in a forwards and upwards direction approximately 30° to the horizontal. The bolts withstood 21 kN with negligible deflection, but at 23 kN the floor panel split and resistance fell as the structure failed. The split is shown on Figure 21.

The outer anchorage was also tested by applying load directly to the bolt and this tore through the floor, also shown on Figure 21, when the load reached 10 kN (i.e. slightly less than the load withstood when tested with the seat). It was concluded that each anchorage could withstand approximately 11 kN and assuming that each anchorage would bear half the total body load, the back seat restraint anchorage could withstand forces of 22 kN acting simultaneously on each of the two backseat occupants.

7.3 Discussion and Summary

The failing loads in these tests are summarized in Table 7.

The anchorages for the lap belt were almost directly below the lap of the occupant when viewed from the side. The lap strap was thus in a nearly vertical plane and was unable to react longitudinal forces until the occupant's hips had moved forwards and the strap tension had developed a horizontal component. Excessive movement of the dummy's hips, especially in relation to the shoulder, allowed the dummy to slip out of the restraint in the static test at a load of approximately 8 kN.

Forwards and downwards loads on the seat frame, which were produced in the test to simulate longitudinal loading of the occupant, resulted in failure of the front cross bar of the seat when the forward load reached 4 kN (5·3 g). After this failure the seat continued to provide support, but the effectiveness of the support was reduced. Forward forces up to 11 kN were applied, but the effect of the rigidity of the body block limited confidence in the applicability of the results to the real life situation.

If the full strength of the restraint could be achieved, the lap and sash anchorages would be able to withstand a forward force in excess of 24 kN (30 g).

A seat back modified to represent the seat base withstood vertical loads of 5 to 6 kN (6–8 g). This force was reached after a downwards compression of the seat into the frame of approximately 100 mm. The fabric seat cover tore round the seat perimeter at that stage and as the body block was thrust further into the seat the springs resisted with a force of about 5 kN.

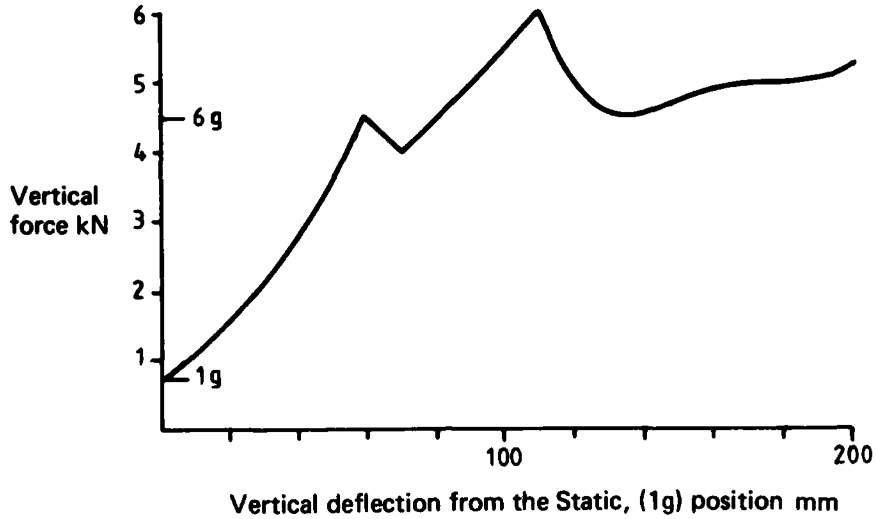


FIG. 20. VERTICAL FORCE DEFLECTION – AIRCRAFT 'C' – SEAT BACK AS SUBSTITUTE SEAT BASE.

FIG. 21. FAILURE OF THE FLOOR AND THE PAIR OF INNER LAP STRAP ANCHORAGES (23kN) AND FAILURE OF THE OUTER ANCHORAGE (10kN) – BACK SEAT AIRCRAFT 'C'

Tests on the rear seat assembly indicated that it could withstand forward forces of at least 10 kN acting on each of the occupants. The assembly was weakened by slotted holes in the foot of the seat, but these may have been cut after manufacture. It is very difficult to see or reach the rear seat mounting bolts and if the seat is removed frequently, to allow extra room for cargo, there would be strong temptation to omit some of the fastenings or to make them easier to fit. In normal use such omission would not be evident nor present a problem however in an emergency the strength would be deficient because under this loading the back bolts are needed to carry the greater part of the load.

Tests of the anchorages in the floor showed that they, and the anchor bolts, could withstand more than 20 kN acting simultaneously on each of the rear seat occupants.

TABLE 7
Summary of Results—Aircraft "C"

Component	Loading	Component failure load kN	Equivalent body block load kN	Equivalent "g"
Front seat and lap belt:				
Forwards load				
Lap belt anchorage	direct	9·2	18·4	24
Lap strap (outer)[1]	direct	7·1	14	18
Seat front cross bar[2]	assembly	—	4	5
Front seat and lap/sash belt:				
Forwards load				
Assembly test—strap slipped[3]	assembly	—	8	10
Sash strap anchorage	direct	11+	27+	30+
Lap belt anchorage (inner)	direct	9·2	23	30
Sash strap	direct	10·8	27	30+
Lap strap (inner)	direct	12·5	30+	30+
Front seat:				
Downwards load	direct	—	5·6	6·6+
Back seat:				
Forwards load				
Inner back seat anchorage[4]	assembly	—	10	13
Outer anchorage	direct	11	22	29
Inner pair of floor anchorages	direct	22	22	29

Notes 1: Inefficient end fitting resulted in low strength—not original equipment.
2: Seat front cross bar failed but system continued to withstand load.
3: Sash strap slipped off dummy.
4: Lug on seat leg failed (may have been modified from manufacturers standard).

8. DISCUSSION ON THE RESULTS OF THE TESTS ON THREE TYPES OF AIRCRAFT

Although the aircraft design requirement for forward loading is only 9 g most of the components of the restraint systems could withstand forces corresponding to 25 g or more. At least one component in each assembly failed at considerably less than 25 g, but they were all small items which could have been designed to withstand 25 g with minimal penalty in cost or weight. In some cases the items did not show the full strength of the aircraft because they had been damaged in the cyclone or were non-standard.

The items which failed at less than 25 g and their relation to the assembly are described below and summarized in Table 8.

(i) Aircraft A. Lap belt strength was limited by the strength of 2 mm rivets in tension. Their arrangement was such that load distribution was not uniform and they failed one after another, like a "Zip" fastener. The strength of the shoulder straps was limited by two very small sheet metal links. These may have been replaced on later models of the aircraft. The short legs supporting the front of the seat collapsed, but the seat was only depressed by about 30 mm. Controlled energy absorbing compression of the seat is desirable, but the collapse which occurred in this test was not sufficient to absorb a significant amount of energy. Space was available for further downwards deflection of the seat.

(ii) All the aircraft of the type B which had been overturned in the cyclone suffered extensive crushing of the cabin, however the seats and lap anchorages were strong, and the only front seat restraint component that failed at less than 25 g was the shoulder strap anchorage. This had probably been fitted after manufacture of the airframe, and could have been stronger if the gusset plate had been longer. The anchorage could not be tested in its correct position, and the strength of the roof could not be determined, because of the damage caused in the cyclone. Cyclone damage also prevented determination of the full strength of the back seat belt anchorages. The inner anchorages withstood the equivalent of 15 g and the less damaged outer anchorages withstood 19 g before a cable linking the belt to the structure failed. It is probable that an intact structure would provide equal strength for all anchorages so that the system would withstand at least 19 g.

(iii) Aircraft C had a very strong cabin and aircraft of this type had been overturned with negligible damage to the cabin structure. The lap strap anchorages were too far forward relative to the seat, and in consequence the slope of the lap strap was too steep. This allowed the hips to move forwards excessively under forwards loading, and also resulted in greater strap and seat loads than would have occurred with a more moderate seat belt slope.

The restraint anchorages withstood forces corresponding to more than 25 g when the restraint was assembled in the lap sash configuration; if used as a lap belt the strength would be slightly less than 25 g. Unfortunately the effectiveness of the restraint may be impaired by the very much weaker seat, as the front cross bar of the seat frame failed at a forward loading corresponding to about 5 g. The seat continued to support the body block in the test while the load was increased to the equivalent of 14 g, but at that stage the clamping of the wooden block between the sides of the seat frame was considered to be completely unrepresentative of the behaviour to be expected with a relatively frail pelvis.

The anchorages provided for the back seat and restraint could withstand more than 25 g acting forwards on both occupants simultaneously, but the seat mounting foot had been weakened by a slot and this resulted in failure at the equivalent of 13 g.

The construction of the aircraft was typical and the anchorages and restraints did not appear to embody more than very local reinforcement or to require structure different in size from that in the surrounding region. Therefore it is considered that strength equivalent to 25 g acting forwards on the occupant could be achieved with little or no penalty in cost or weight.

The seats of two of the aircraft (A and C) suffered partial collapse as a result of quite low forward forces (less than 6 g). After the partial failure the seat belt and seat assembly continued to resist forwards loading, but the geometry was affected adversley. In one case testing with the large flat body block, as described in an aircraft standard, would not have identified the weakness in the cross bars of the frame, because it would have loaded the seat legs directly.

Vertical loading produced large deflections in the springs or seat pan. The seats tested withstood the required 6 g (see Table 9) before the fabric covering failed, but apparently the fabric, padding and springs all helped to react the load. The deflection characteristics are important as well as the maximum strength, and dynamic tests to determine the performance under crash load are desirable. Dynamic testing of seats from aircraft B and C is proceeding and will be the subject of a report.

TABLE 8

Summary of Results—Failures at Forwards Loads of less than 25 g

Aircraft Type	Installation	Component	Loading (g) at failure	Comment
A	Front seat, restraint	Lap anchorage	21	Rivets in tension failed
	Harness	Shoulder link	21	Links very small
	Lap belt restraint	Seat	6·3	Partial collapse not critical
B	Front seat lap sash restraint	Sash anchorage	13	Probably not original installation
	Back seat	Lap belt anchorage, outer	19	
		Lap belt anchorage, inner	15+	Two occupants loaded at once, structure damaged before test
C	Front seat, lap belt	Belt	18	Not original equipment
		Lap belt anchorage	24	Anchorage pulled out
		Seat cross bar	5	Partial failure
	Front seat, lap sash	Seat cross bar	5+	As above
	Back seat	Inner anchorage	13	Probably weakened by modification

TABLE 9

Seat Strength—Maximum Resistance to Downwards Load

Aircraft Type	Installation	Loading kN	Comment
"A"	Seat	—	No test
"B"	Front seat	13	Natural fibre webbing, straps failed
"C"	Front seat	6·6	Seat covering failed, springs yielded

9. CONCLUSIONS

Most of the aircraft had been turned over in the cyclone, but the cabins of the high wing aircraft generally survived with little damage. The cabin roofs of nearly all the low wing aircraft had been crushed.

The tests showed that:

1. Most of the components of the restraint system could withstand forward acting forces corresponding to 25 g on an occupant of mass 77 kg.
2. Failures at forces corresponding to less than 25 g were usually in:
   (a) small detail fittings, or
   (b) fittings which had been damaged in the storm, or
   (c) fittings which were not original equipment in the aircraft (e.g. shoulder strap anchorages).
3. Partial seat failures and excessive deflections occurred at forces very much less than those which produced failure in the restraints.
4. The flat bottomed body block recommended in some standards would not have shown weaknesses in the seat which were identified using a more realistic body block.
5. Large deflections of the seat under vertical loading made static testing an unreliable predictor for crash (dynamic) performance.

From these results it was considered that:

(1) Light aircraft restraints could be designed and manufactured to withstand forces corresponding to 25 g forwards with minimal alterations to the aircraft or weight or cost penalty.
(2) The body block used in testing seats and restraints should have a representative width and shape.
(3) The effects of vertical loading require further investigation and seats should be tested dynamically.

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APPENDIX

Load Distribution in the Restraints

1. POSITION OF THE LOADING YOKE ON THE BODY BLOCK

The distribution of the load between the lap and sash straps of the restraint by the body block depends on the position of the loading yoke on the torso frame (Fig. 2). To find a position which would give realistic load distribution, the body block was fitted into a seat and restraint assembly which had been used previously for dynamic testing with an anthropometric dummy (Alderson VIP 50).[19,20] A series of static tests was conducted with the position of the yoke being adjusted until the distribution of load agreed with that measured in the dynamic tests. The agreement was found satisfactory for two alternative lap strap geometries when the yoke was in position G. Results are shown in Table 10. This point, 305 mm from the seat base, is higher than suggested by the seat standard, but is considered appropriate to this unusual body block.

Table 10 also shows that although the straps were not parallel to the applied load, the sum of the strap loads was very nearly equal to the applied load.

TABLE 10

Load Distribution in Dynamic and Static Tests

Peak acceleration of sled in dynamic test 120 m/s^2
Load point G in static test (see Fig. 2)

Test condition		Total strap load T kN	Proportion of total strap load			Static load A kN	$\frac{T}{A}$
			Sash $\frac{S_s}{T}$	Inner lap $\frac{S_i}{T}$	Outer lap $\frac{S_o}{T}$		
Geometry 1[1]	dynamic	15·9	0·32	0·44	0·24	—	—
	static	13·9	0·31	0·43	0·26	12·5	1·07
Geometry 2[2]	dynamic	13	0·38	0·38	0·24	—	—
	static	12·9	0·38	0·38	0·24	12·8	1·01
Geometry 3[3]	(lap belt) static	12·7	0	0·46	0·54	12·7	1·0

Notes 1: Lap sash assembly, lap strap anchored at seat level.
2: Lap sash assembly, lap strap anchored at floor.
3: Lap belt only anchored at floor, slope 60°.

2. LOAD DISTRIBUTION IN THE RESTRAINT AS MEASURED IN THE CABINS

The load distribution in the straps of the lap sash assembly, tested in the high wing aircraft and shown in Table 11 was similar to that measured on the rig with floor anchorages as shown in Table 10 (note the seat height for the rig was originally based on the aircraft layout).

TABLE 11

Load Distribution, High Wing Aircraft Cabin Test

T kN	$\frac{S_s}{T}$	$\frac{S_i}{T}$	$\frac{S_o}{T}$	A kN	$\frac{T}{A}$
7·6	0·37	0·39	0·24	8·0	0·95

Note: Notation as for Table 10

3. SUMMARY

In most of the tests the sum of the strap loads was very nearly equal to the applied load, the only exception being the lap assembly on the low wing aircraft, when the sum of the strap loads was consistently 0·8 of the applied load.

To estimate the loads in a system with a geometry similar to those tested, a typical distribution is suggested in which the load in the sash and inner lap strap are 0·4 of the applied load and that in the outer lap is 0·25 of the applied load. To estimate the strength of the assembly from its components it is suggested that the allowable load on a lap sash assembly is the least of the following:

2·5 times the sash strength

or 2·5 times the inner lap strength

or 4 times the outer lap strength

The allowable load on a lap belt assembly may be taken as the lower of:

twice the strength of the inner lap strap

or twice the strength of the outer lap strap.

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